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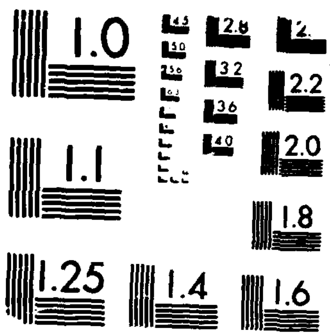

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Noise Generation and Boundary Layer Effects in Vortex-Airfoil Interaction and Methods of Digital Hologram Analysis for these Flow Fields

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For the generation of impulsive sound waves caused by parallel interaction of a vortex and an airfoil in a plane flow field, two different mechanisms are responsible by experimental evidence. The first one originates from the area of the stagnation point of the airfoil: a temporal increase of pressure and density - in consequence of the incoming vortex - relaxes by sound wave emission, when the vortex vanishes behind the airfoils nose. This is called a compressibility wave. The second one is reasoned by a supersonic flow regime, which appears, when the stationary airfoil flow is augmented by the flow field of the vortex: at the shoulder of the airfoil we get an unsteady return to subsonics by a shock wave. This moves upstream after the vortex has passed and is named transonic wave. Evidently both mechanisms only occur, if the flow field at the airfoil is augmented by the vortex, i.e. the vortex has a special spin orientation with respect to the airfoil.

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Noise Generation and Boundary Layer Effects in Vortex-Airfoil Interaction and Methods of Digital Hologram Analysis for these Flow Fields

ABSTRACT

For the generation of impulsive sound waves caused by parallel interaction of a vortex and an airfoil in a plane flow field, two different mechanisms are responsible by experimental evidence. The first one originates from the area of the stagnation point of the airfoil: a temporal increase of pressure and density - in consequence of the incoming vortex - relaxes by sound wave emission, when the vortex vanishes behind the airfoils nose. This is called a compressibility wave. The second one is reasoned by a supersonic flow regime, which appears, when the stationary airfoil flow is augmented by the flow field of the vortex: at the shoulder of the airfoil we get an unsteady return to subsonics by a shock wave. This moves upstream after the vortex has passed and is named transonic wave. Evidently both mechanisms only occur, if the flow field at the airfoil is augmented by the vortex, i.e. the vortex has a special spin orientation with respect to the airfoil.

1. Vortex-airfoil interaction

A primary result for parallel BVI is found in the orientation of the vortex spin to the airfoil. Regarding the center line in an image, respectively an imagined prolonged airfoil axes, the advancing vortex can have an account towards or away from the leading edge. The difference is, that in the first case the velocity field of the vortex is added to the airfoils flow field, otherwise it is substracted. By this we are able to distinguish between two fundamental kinds of BVI in a system, where vortex and blade have parallel axes.

Our preliminary experiments show - in accordance with the mechanism explained later - impulsive sound wave generation merely, if the vortex rotates towards the airfoil. As a model for Helicopter Blade Slap this is the important case of BVI. The tip vortex in the downwash of an helicopter will rotate towards the next rotor blade.

Two processes of sound wave generation have been recognized yet; these are named compressibility and transonic waves. They can easily be distinguished by their different origins at the airfoil.

The compressibility wave appears as an upstream propagating region of closed interferometric fringes in front of the airfoil. This type of soundwave has been discribed in the first interim report.

At next we put interest to the unsteady jumps in the interferometric fringes - and thus in density - occuring under the airfoil as the vortex has passed by. Two or more of them are noticed: a cascade of shock waves. They propagate upstream and it is supposed that they merge in the far field.

These results already bear the information for a physical explanation, but further quantitative evaluations have been done to approve this description.

2. Image processing and analysis

Initial evaluations can be done by semi-automatic image processing: the border lines of the interferometric fringes are extracted and numbered according to the density gradient. Afterwards the whole density field can be computed by using interpolation and be printed, where density is shown in the vertical axes. We obtain 3-dimensional plots, which correspond to interferograms. The printed surface shows a density niveau, but for barotropy this is similar to the pressure: a depression for a region of low pressure, e.g. a vortex, and an elevation for a region of high pressure, e.g. the stagnation point.

3. Vortex generation system

We make use of vortices from a Karman vortex street. In order to enlarge the spatial distance of the vortices, we accelerate the whole duct flow after vortex production. By these means the whole vortex street is stretched and the interaction can be observed with a separated test configuration.
Further we utilize duct modes to stimulate the vortex shedding. The acoustic energy emitted during the vortex shedding procedure is brought to resonance with transverse duct oscillations. This feedback mechanism is able to synchronize the shedding process and to enlarge the vortex strength. Present investigations concern a quantitative research and will be reported next.

4. Evaluations

New results concern the investigation of transonic waves. Notably, the decrease of pressure at the shoulder of the airfoil is greater than it would be when caused either by the flow around the airfoil or by the vortex alone. The flow-fields of the vortex and around the airfoil are superposed and thus receive a supersonic value. There is the usual unsteady return to subsonics by a shock. Travelling along the airfoils shoulder, this process is repeated (instationarity is also local, since the flow fields are bound to the airfoil as well as to the vortex). Two shocks can easily be observed in this example (other pictures show three of them and indicate more). As part of the instationary character of BVI, the supersonic flow regime vanishes. The shocks move upstream - when the vortex is travelling on - and leave at the airfoils nose as shock waves.
Further we tried to get more detailed information and obtain a comparison to far-field studies of rotors. Therefore the pressure signal was derived, but these results are fairly approximative, because the interferometric fringes give only discrete values and assumptions like quasi-stationary, isentropic flow are not right in this case; there are almost everywhere boundaries in our duct, so that our "far-field" is influenced by them. Nevertheless Fig.2 shows the signal of the discussed sound waves. It was derived from an image series where both wave types are clearly visible. To avoid disturbances from the vortex street, evaluation was done along a line from the leading edge upstream with 45 degree inclination to the center line. There are some hints for a directivity, but as we have to consider effects of the plane duct flow, the

travelling vortex street below and the limited view by the images enclosure, we will not stick to it. Roughly it is to state, that compressibility waves propagate above the center line, whereas the transonic waves expand radially from the airfoils nose.
Quantitative evaluation can be obtained for transonic waves, since the shock front is precisely to locate in an image. Fig.3 and 4 show the trajectory of the first shock on the center line upstream. The data is already nondimensionalized and thus shows clearly the characterizing influences.
Since the generating process happens within less than 10% of the temporal distance between two vortices, it becomes obvious that only a single vortex is responsible for the mechanism. Then the shocks start within the first 20% of the airfoils length, which makes sure that only the region close to the airfoils nose is needed here.
Differences can be noticed in Fig.3 depending on an encreased circulation. The relevant region at the airfoil enlarges according to the circulation of the interacting vortex, which agrees with an more extended supersonic flow regime in this case. (In fact, the differences in Machnumbers are too low to explain the discrepancy.) There is a time delay for stronger vortices, which relates to this extension at the airfoils profile as well as to an extended vortex itself.
By these graphs we obtain also the shock Machnumbers, which enables us to compute approximately the shock strength. The shock Machnumbers vary between 1.02 and 1.09 and the density jump can be estimated as half of an fringe order. With the Rankine-Hugoniot equation this leads to a relative pressure jump of about 1%, i.e. the entropy will change in magnitude of 10^{-6}. Thus we dare to speak about rather weak shocks, which become real sound waves. As suggested by Fig.2, they merge with the compressibility wave in the far field.
This statement is important for a comparison to results from the shock tube [Timm 1985]. In those experiments one very small vortex interacts with an airfoil and only one generated sound wave is observed. Presumably it is based on the very short temporal distance for both effects in this case and a quick unification of both waves.
Afterwards we started experiments with different curvature of the airfoils profiles. Fig.4 shows the used airfoils and the obtained data. In general there is no clear difference visible, apart from the strongly bowed side of VR 7 towards the vortex row. But this agrees with our local argumentation for impulsive sound generation: the area, relevant for interaction, extends for a vast bow towards the vortex and thus causes the same as an enlarged vortex or slower interaction. Last experiments with inclined airfoils agree to this.
The dependence on the flow Machnumber was not definitely explored, since the preparing of a vortex in this experiment depends on special relations. Even the vertical distance between the center line and the vortex street is not easy to predict, as far as there are changes of a Karman vortex street in duct flows unexplained until now. But there is a changed behavior for sound mechanisms, when the vortex rotates away from the airfoil. For the described mechanisms no events have been found in this case, yet.

5. Personnel

In addition to the others we won U. Schievelbusch for experimental work and Dipl.-Phys. St. Koch for evaluation. Dipl.-Phys. G. Shi left the group.

6. Reference

Timm, R. (1985): Schallentstehung bei der Wechselwirkung von Wirbeln mit einer Tragflügelumströmung, Mitteilungen des MPI für Strömungsforschung Nr.80

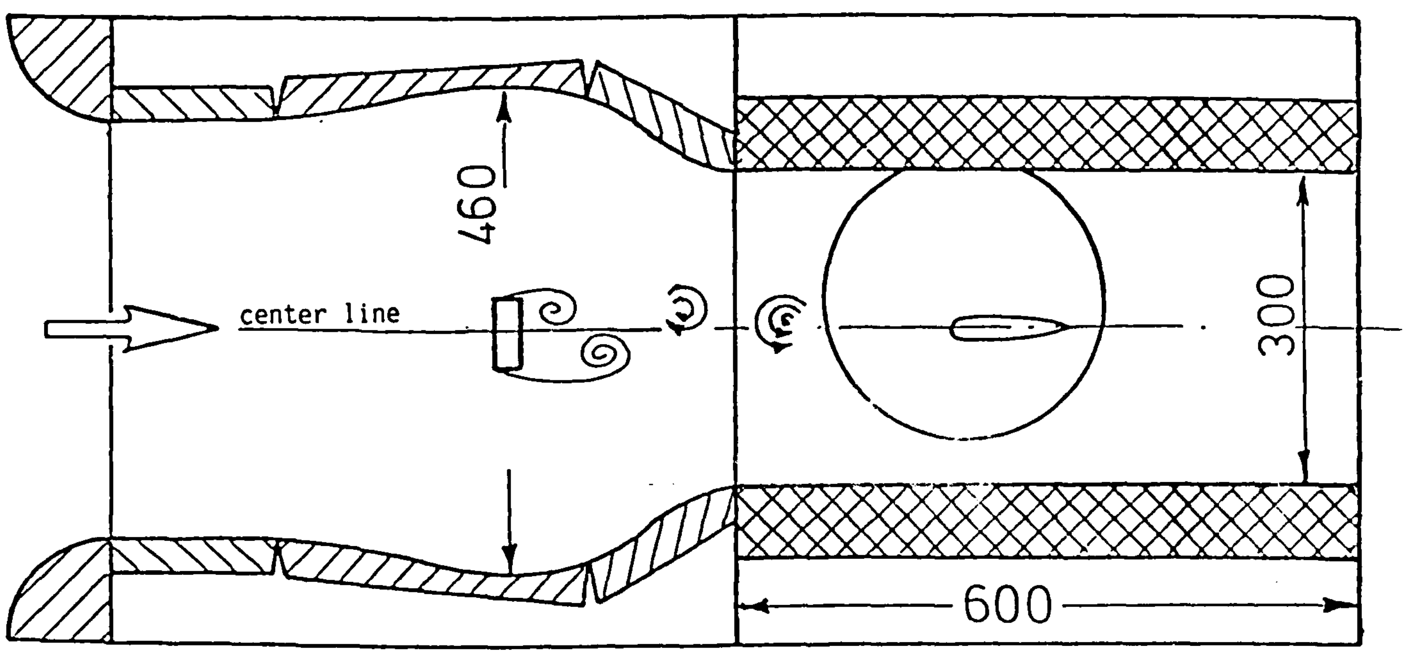


FIGURE 1: Test section. - Vortex generation and vortex-airfoil interaction.

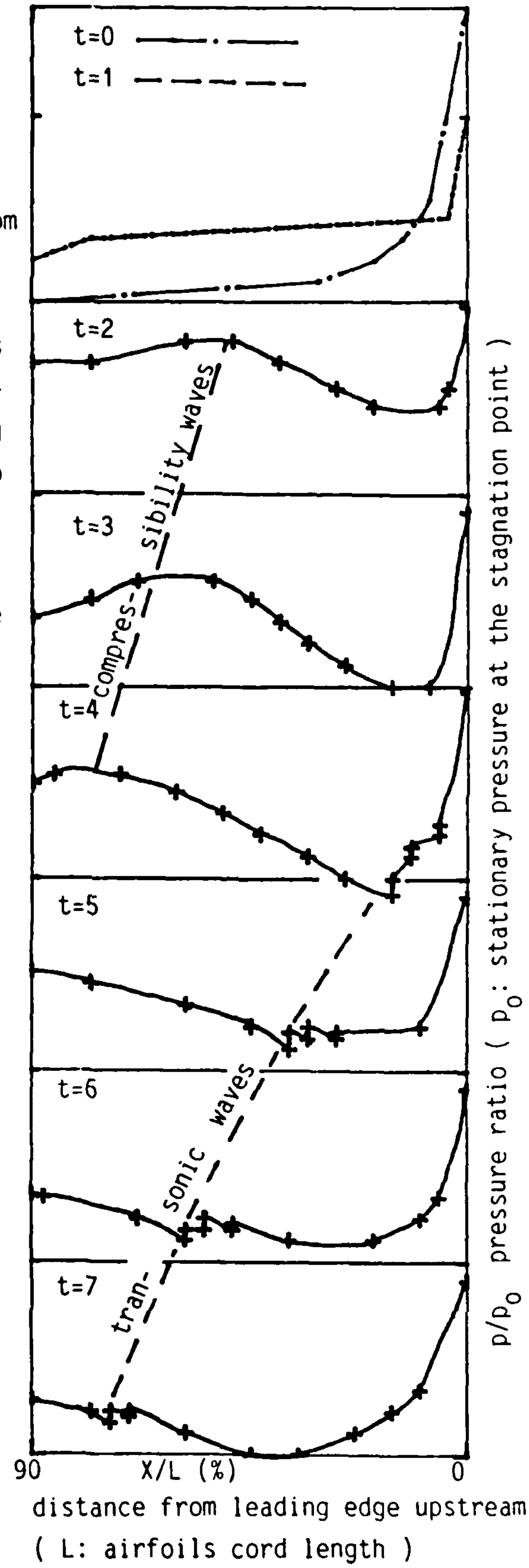
FIGURE 2:

Upstream propagating sound waves. Interim time 0.1msec each step.

The pressure was derived from the interferometric fringes assuming isentropic flow.

The airfoils leading edge is at the right side and evaluation is done upstream along a line inclined 45 degree to the center line to avoid influences of the vortex.

Within the visible emclosure the compressiblity wave steepens and is approached by the transonic waves.



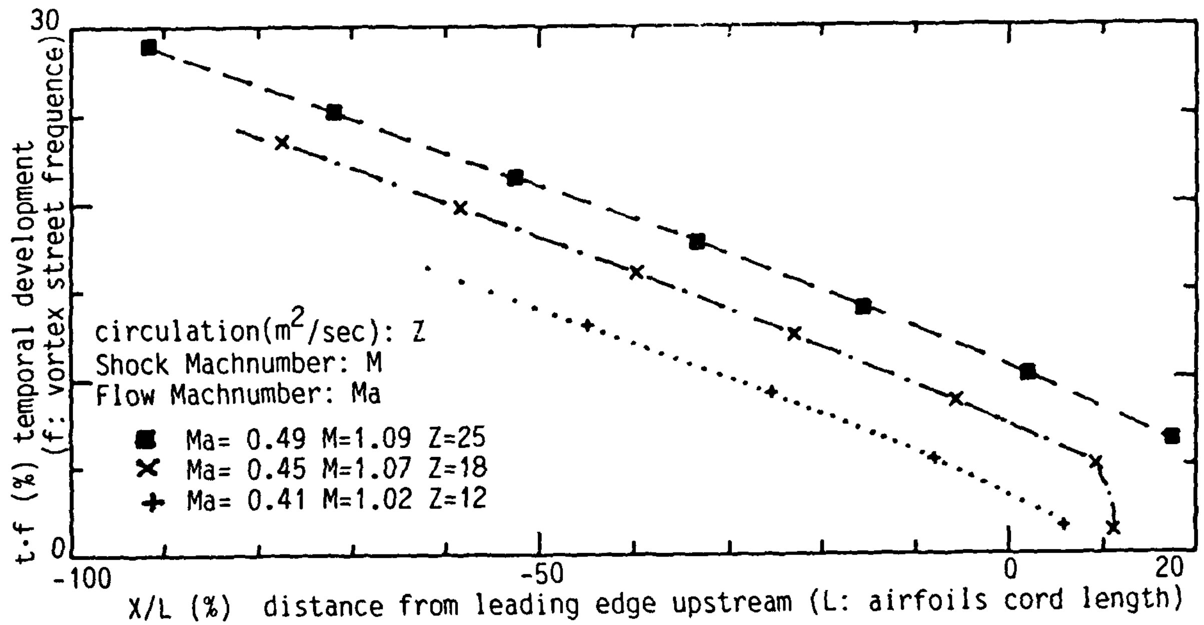
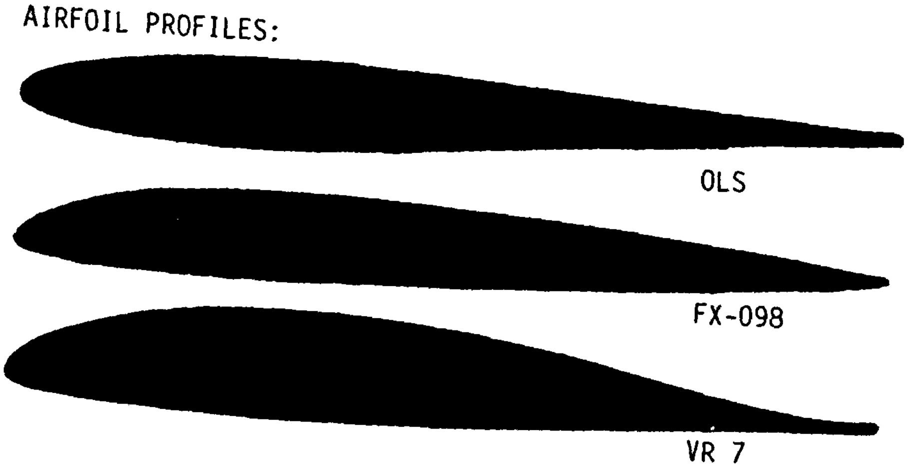


FIGURE 3: Trajectories of the first shock front upstream on the center line.
Influence of the vortex strength on transonic waves (airfoil: OLS).
A higher circulation causes a time delay for the shock generation.



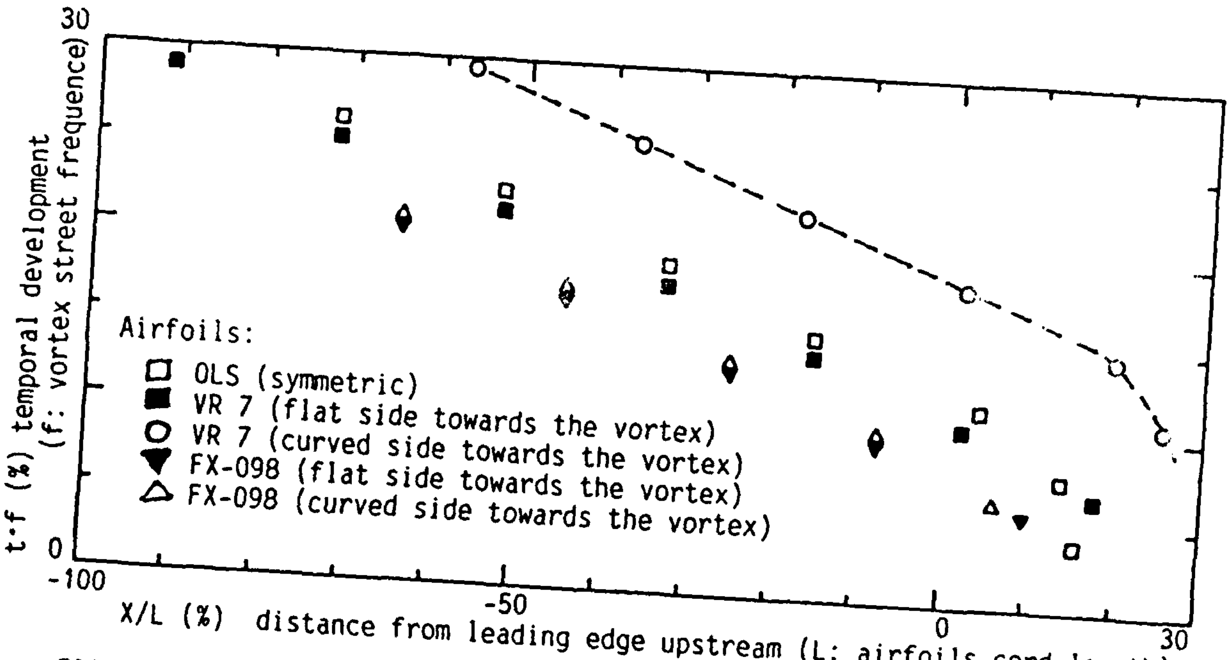
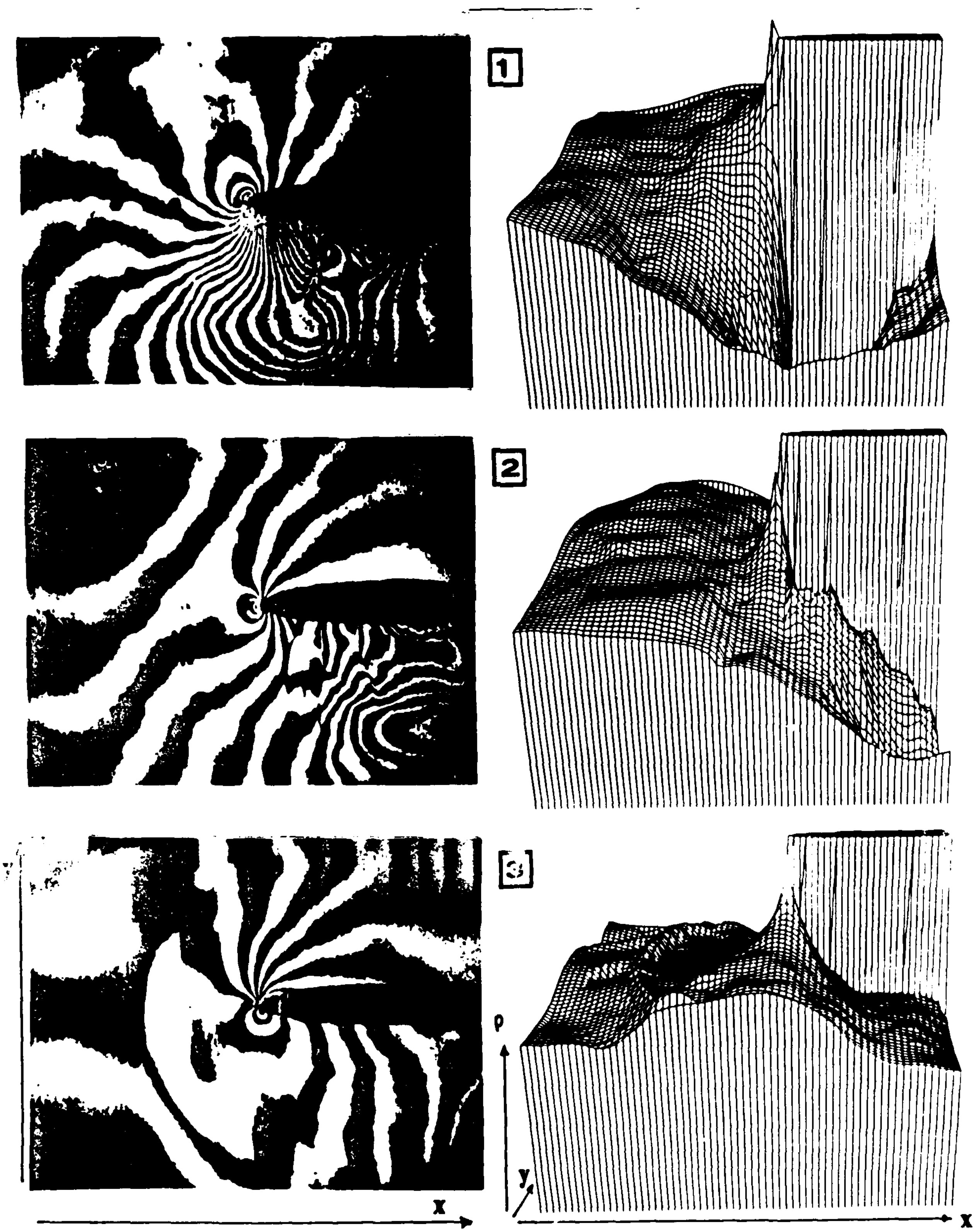


FIGURE 4: Trajectories of the first shock front upstream on the center line. Importance of the airfoil shapes (Ma= 0.49; circulation: $25m^2/sec$). Significant effect for the strongly curved surface of airfoil VR 7.

Transonic Waves



AIRFOIL OLS (cord length L=12cm)
Ma=0.5 Circulation: $\frac{\Gamma}{UL}$= 3.6
Interframe time: 0.20msec

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